<u>INDY ROBOT RACING TEAM</u>

DARPA Grand Challenge 2005

Technical Paper

Initial Issue 1.0

August 29, 2005

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ABSTRACT

Effective, medium-speed (0-30mph) mobile robot control is demonstrated using a distributed hierarchical control paradigm with complementary sensor redundancy. This implementation reacts quickly to unpredictable environmental anomalies while offering graceful system degradation. A two axis stabilized platform provides mounting for all field view sensors with attached proprioceptive sensing for accurate transformation of sensed data to the global frame.

INTRODUCTION

IndyRobotics, LLC, parent company of the Indy Robot Racing Team, was founded by business owners in the Indianapolis area to promote robotic development in Indiana. The company's President / CEO, Scott Jones, is one of Indiana's most prominent technology leaders. Doug Traster, official team leader, and 105 other members, work in distributed teams to develop the technology required for the DARPA Grand Challenge. In addition, a number of generous sponsors have provided support in the form of equipment, services or funding. While the team's short-term goal is to perform well at the Grand Challenge, Indy Robotics LLC hopes its success will create a greater focus on Indiana's talented engineering and robotics community and position the state for greater high-tech industry growth.

Pooling the resources of well-known Indiana universities including Indiana University, Purdue University, and Rose-Hulman Institute of Technology with technical professionals throughout Indiana, the Indy Robot Racing Team represents a "Dream Team" of top engineers and robotics experts in the state of Indiana.

With a successful completion of the DARPA Grand Challenge, IndyRobotics, LLC and the Indy Robot Racing Team will define the future direction of the robotics industry. The Grand Challenge provides a platform to showcase the capabilities of autonomous vehicles.

1. Vehicle Description

1.1. Indiana's Robotic Vehicle (IRV) sits on a 2004 Jeep Rubicon platform. The Rubicon is specifically designed for off-road driving, has a heavy duty chassis, front and rear locking differentials and high ground clearance.
Length: 156.1 in., Width: 68.2 in., Height: 72.1 in., Weight: 3438 lbs.
Wheels: 30 in., Turning Radius: 15 ft., Power Plant: 4.0 L16 Engine
Torque: 235 ft-lbs@3200 RPM, Fuel/Capacity: Unleaded/19 gal.

1.2. IRV is equipped with an Ahnafield Corporation drive-by-wire (DBS) system designed to enable mobility for the physically handicapped. The DBW and its associated vehicle control system (VCS) provide triple redundancy for steering and braking, throttle safety release and ignition cut-off. A backup alternator attached to the vehicle engine and an independent 6500 watt generator mounted on the back of the vehicle handle the power requirements for computers and electronics.

2. Autonomous Operations

2.1. Processing

2.1.1. Thirty IBM T23 laptops (Windows 2000) and five Compaq Armada M700 laptops (Linux OS) use a multi-cast messaging protocol to interface modules. Automatic failover and graceful degradation are built into the architecture.

2.1.2. See Figure 1 and Figure 2 for a functional block diagram of the processing architecture.

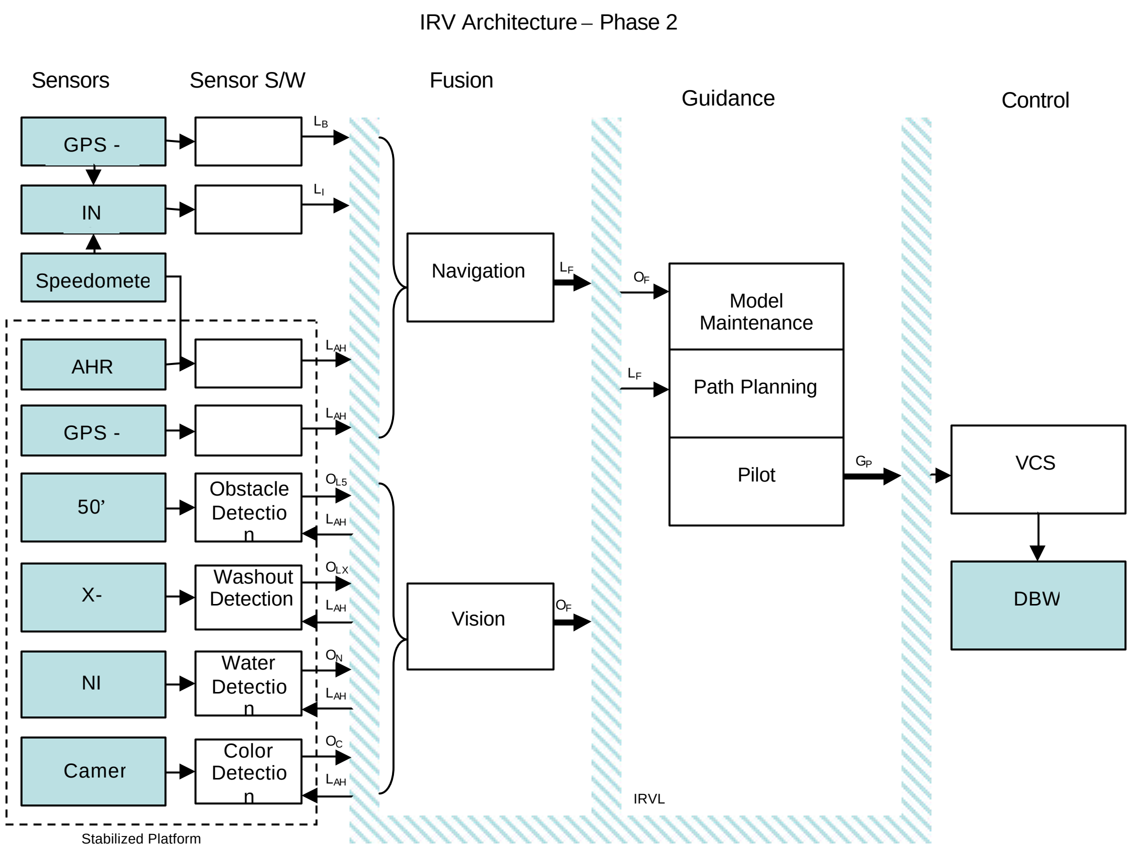

Figure 1 – System Architecture

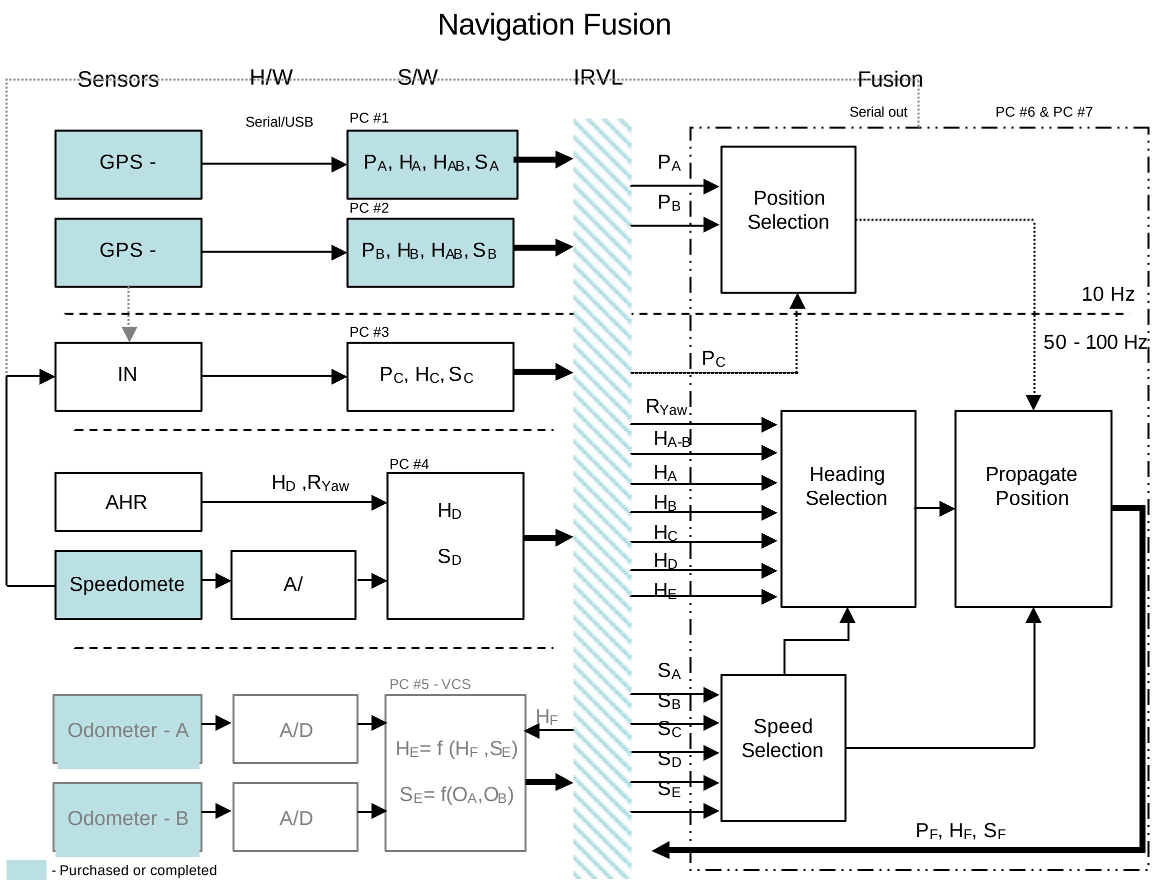

Figure 2 – Localization Fusion Architecture

2.1.3. The processing architecture is fully distributed with no central manager. Each module is isolated in a single laptop PC to limit software interaction and to allow a "plug & play" of individual components.

2.2. Localization

2.2.1. Three Differential Global Positioning System (DGPS) units provide positional information. Two NAVCOM Technologies Model SF-2050M units with Starfire™ differential correction and one Trimble Ag252 with Omnistar VB™ enhancement are widely separated to assure fail-over integrity and to identify GPS error sources. When DGPS outages occur, IRV is designed to revert to one of three dead reckoning systems: Inertial navigation using IXSEA PHINS and O'Connor Engineering Doppler RADAR, IXSEA OCTANS fiber optic gyrocompass systems and vehicle speedometer, or dual differential odometry wheels. Each of the dead reckoning systems is designed to allow the vehicle to travel up to ½ mile with a track error of less than 10 feet. Coupled with road position aiding from the sensing system, the vehicle will be able to operate for significant periods in the absence of DGPS.

2.2.2. Topological map data provides elevation information to control vehicle speed in secular inclines and declines.

2.3. Sensing

2.3.1. All sensing equipment is mounted to an instrument platform stabilized in pitch and roll. Platform pivot points near the vehicle's center of rotation reduce translational movement. LIDARs, cameras and scanning radar constitute the sensing infrastructure. SICK Corporation LMS 291 scanning LIDARs are oriented in various ways to enhance environment profiling. Two units form a vertical "X" in front of the vehicle to detect terrain contours and road edges, one is oriented vertically and straight ahead to detect inclines and declines and eight are placed horizontally at different distances for road edge and obstacle detection. A shroud covers each LIDAR to block direct sunlight, eliminate off-axis returns from other LIDAR units and to provide cooling. The shroud utilizes a ram scoop to funnel air at a high velocity to the unit's lens to remove dust. Each of the four cameras perform a unique function: color feature detection, water detection, road finding and localization aiding using optical flow for detecting IRV's speed and orientation. A videocam modified by MaxMax.com to enhance infrared sensitivity is used for water finding. An Epsilon-Lambda 3D scanning radar provides 40° horizontal field of view, 7° vertical field of view at 5Hz.

2.3.2. Complementary sensor fusion provides data to the system in each of four categories: obstacle detection, terrain profiling (road finding), localization and vehicle health. The model for localization is primarily based on voting and fail-over strategies. Some of the sensors are motion dependent and the value of their inputs (confidence factor) is modified by vehicle state. Health fusion heuristics determine conditions for partial system shutdown or vehicle slowdown actions. The obstacle and terrain profiling heuristics fuse disparate data from multiple sensor types to define a property set for each external environment feature. The sum of this property set which includes size, distance, color, density, reflectivity, texture, position and other features, defines the feature for the global vehicle model. This, in turn provides information to path planning and pilot software.

2.3.3. Internal vehicle state is monitored by an array of sensors: voltage and current monitoring, OBD-II interface for engine information, shock / vibration sensors for detection of excessive movement in the shock mounted instrument racks and temperature sensors for both localized and ambient conditions. Input from these sensors may result in vehicle slowdown or partial system shutdown.

2.3.4. Steering is implemented with triply redundant closed loop servomotors guided by a dynamically adjusted pursuit algorithm modified for a variety of exception conditions such as “off track error”. The path followed by the pursuit algorithm is defined in priority order by obstacle avoidance, road sensing and waypoint following. Throttle is controlled by a speed based PID loop using a linear actuator on the accelerator cable. The system manually downshifts (transmission is automatic) to implement engine braking in a steep decline. Normal braking is part of the speed control loop.

Under E-Stop conditions, an air brake stops the vehicle even without active vehicle electronics.

2.4. Vehicle Control

2.4.1. Waypoint satisfaction occurs anytime the vehicle has passed over the line perpendicular to the waypoint track at which point, IRV will proceed to the next waypoint. IRV will detect if it is in a vehicle stuck mode. This is determined by comparing wheel speed vs. ground speed. IRV will attempt reverse for a brief distance and resume forward to desired path route.

2.4.2. Braking is applied whenever the current speed exceeds the desired speed by 5 mph or more. Speed commands include a desired acceleration rate that defines the level of braking required. A PID loop adjusts braking pressure to achieve the desired acceleration rate until the desired speed is achieved. When starting on a hill, a desired speed and acceleration rate command is given. Throttle is applied and the PID loop gradually increases the throttle until the desired acceleration is achieved. The throttle is retarded once desired speed is achieved. IRV can make a sharp turn without leaving the route boundary because all maneuvers performed beyond 0.7 lateral boundary offset (LBO) off centerline are based on 5 mph speed and full lock steering back to the desired track.

2.4.3. All navigation data is processed through a navigation fusion module responsible for using confidence level information to determine which of the several sources of data on each parameter are the most reliable. Nav Fusion then publishes position, heading, speed, acceleration and other information at a 100 Hz rate. For example, the speed source selected could be outboard odometry (below 5 mph), Doppler radar (above 5 mph), GPS (if no other source is available), or vehicle speedometer (if no other source is available). Sensor information is converted to the global frame of reference (latitude/longitude/elevation) before publishing. All message information is integrated in the Model Maintenance database, which publishes the integrated local model to path planning.

2.4.4. When IRV is not in autonomous mode, the vehicle operates as a standard, human driven automobile.

2.5. System Tests

2.5.1. IRV is equipped with a 2-Tier Power System that provides multiple redundancies in case of a power failure, see Figure 3. Indy Robot Racing team has constructed an obstacle course similar to the DARPA Grand Challenge 2004 QID. IRV has numerous obstacles to encounter in order to plan for unforeseeable events while testing in the California desert. The testing course is equipped with a route path that is similar to desert terrain. The course has about 45 boulders (fake rocks), 32'x10'x9' tunnel section (shielded to block GPS), two static cars, 2 tank traps, gate posts to simulate "choke points", dirt moguls (various sizes) to provide rough terrain, 20°+ dirt hill, imitation concrete barriers, berms and a cattle guard.

2.5.2. Endurance runs have been completed to calculate fuel consumption while IRV was under a full system load. The best endurance run as of 8/29/05 ran a continuous 105 miles in 6 hours under full autonomous mode on the obstacle course. There was sufficient power budget to comfortably complete the 175 mile course within the 10 hour limit.

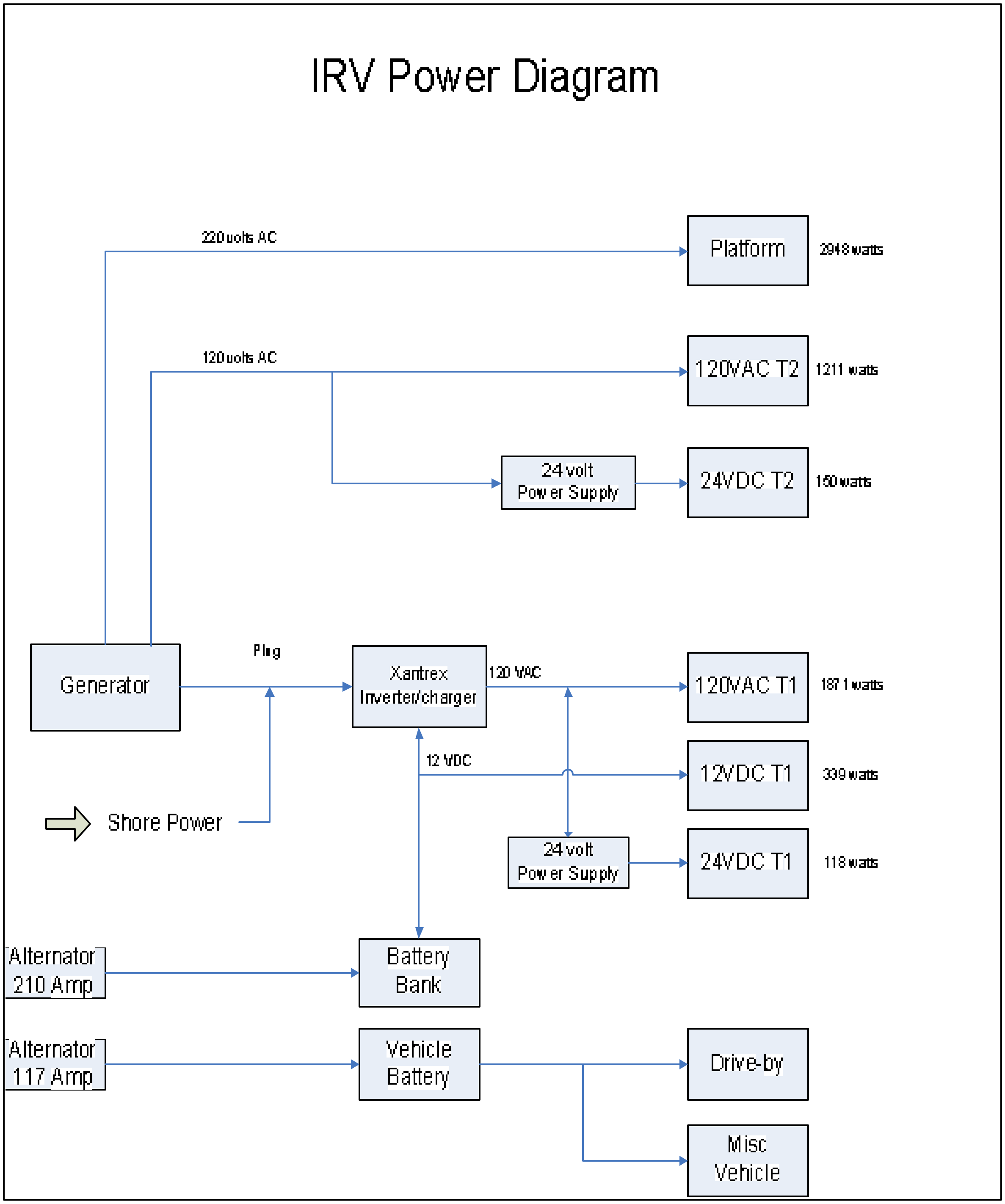

Figure 3 – Vehicle Power Management